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PORTON TECHNICAL PAPER No(R) 46

THE INFLUENCE OF SMOKE LAYER DEPTH ON THE ATTENUATION OF LIGHT IN A SIMULATED SCATTERING ATMOSPHERE [U]

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BY

N.W. WOOTTEN and W.R. LANE

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PORTON TECHNICAL PAPER (R) 46

DATE: September, 1962.

THE INFLUENCE OF SMOKE LAYER DEPTH ON THE ATTENUATION OF LIGHT IN A SIMULATED SCATTERING ATMOSPHERE

by

N.W. WOOTTEN AND W.R. LANE

SUMMARY

Measurements of the flux received by variously orientated surfaces from an omnidirectional light source in smoke layers of different depths are presented and discussed.

It is shown that the attenuation of the flux incident on a forward facing surface in a smoke layer of given vertical transmission is constant for a given source distance/smoke layer depth ratio. This does not apply in the presence of a reflecting ceiling which enhances the flux in all measurements, nor to surfaces facing in other directions.

The data have been related to a limited series of field measurements to derive a scaling factor which might be used to predict the flux likely to be received under other conditions in the natural atmosphere.

(Sgd.) H.L. Green,
Supt., Physics Research Division.

(Sgd.) A.S.G. Hill,
Deputy Director.

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THE INFLUENCE OF SMOKE LAYER DEPTH ON THE ATTENUATION OF LIGHT IN A SIMULATED SCATTERING ATMOSPHERE

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INTRODUCTION

A previous paper (1) contained a report of measurements of the flux received, in the presence of a shallow layer of smoke, by a plane surface at ground level from an omnidirectional light source on the ground or in the air. The layer had the same depth in all the experiments. By careful control of the conditions in the chamber it has been possible to produce smoke layers of various depths and to study the effect of this depth on the flux received.

Due to the large number of variables involved the present investigation has been confined to two boundary conditions (a) floor and ceiling absorbing and (b) floor absorbing and ceiling reflecting. These represent the environmental conditions most frequently encountered (viz., ground of low albedo and clear or cloudy sky) and for which the greater number of field measurements are available (2).

The earlier report (1) suggested the introduction of a "scaling" factor to relate the then available field measurements with those made in the chamber for one smoke layer depth. A more detailed analysis of the field measurements is now available (2) and by suitable scaling the chamber results can be related to measurements at greater field distances.

EXPERIMENTAL PROCEDURE

Full details of the instrumentation and experimental arrangements have been previously reported (3) and only a brief outline will be given here.

The smoke chamber was a closed room (10.6 m x 6 m x 2.8 m high) normally having matt black walls, floor and ceiling. A reflecting ceiling, when used, was of white, diffusing paper (albedo 0.5) suspended 1.5 metres above the floor. The source, which produced an almost spherically symmetrical illumination and was water-cooled to prevent convection within the smoke, was placed on the floor. Photovoltaic cells and photomultipliers, both covered with ground opal diffusing screens, were also placed on the floor at various distances from the source, some vertical - facing towards or away from the source - and others horizontal - facing upwards. The photo-currents were measured with a sensitive galvanometer.

A stable smoke layer near the floor was produced by passing fog-oil smoke through crushed solid carbon dioxide. The smoke was gently stirred with an array of fans; the degree of stirring determining the height to which the top of the layer rose. With fairly shallow layers (up to 0.5 metres thick) the depth remained steady throughout the experiment, which lasted about two hours, while the smoke concentration fell from about 1.5 g/m^3 to a very low value. The change in droplet-size distribution occurring during this time has been shown to have very little effect on the diffuse transmission (4). With thicker layers there was a gradual sinking of the top of the layer the depth of which was noted by means of a vertical scale in the chamber. A collimated-beam transmissometer was used to measure the attenuation coefficient of the smoke which was adopted as the parameter to characterise the smoke in the various experiments.

In all, 24 experiments were carried out (11 with the absorbing ceiling and 13 with the reflecting ceiling). They covered smoke layer depths from 0.25 to 2 metres and distances up to 8 metres from the source. The range of attenuation coefficients was 0 to 5 $metres^{-1}$.

RESULTS

To facilitate the presentation of the results symbols have been given to the parameters that are to be discussed.

C = the height of the reflecting ceiling in metres.
H = smoke layer depth in metres.
R = ground range from the source in metres.
I_o = the flux in the absence of smoke.
I = " " " " presence " "
σ = the attenuation coefficient in metres $^{-1}$.
σ_H = " " " " terms of the smoke layer depth.
$R/_H$ = ground range in terms of the smoke layer depth.

The first step in the assessment of the measurements was to plot, for each experiment, the observed photocurrents, the smoke layer depth and the collimated transmissions against time. From these graphs the smoke layer depth and flux (in arbitrary units) could be found for given values of the attenuation coefficient. (The latter is obtained from the relation $T = \exp(-\sigma x)$; where T is the collimated transmission and x is the path length - in this case 1 metre).

(a) Surfaces facing the source

It is now possible to relate the various experiments by plotting I/I_o against H for various values of R and σ. These graphs are given for the surfaces facing the source with an absorbing and reflecting ceiling in Figs. 1 and 2 respectively.

The effect of the scattering within the smoke is better demonstrated in Fig. 3 where I/I_o has been plotted against R/H in terms of σ_H. This shows that I/I_o is constant for given values of R/H and σ_H and means that if the smoke layer depth and the distance from the source are doubled whilst the smoke concentration is reduced to give the same optical thickness the value of I/I_o remains the same. It must be remembered, however, that I_o is reduced, in this case to 0.25 of the original value, by the inverse square law.

From Fig. 4 it is seen that for a reflecting ceiling this relationship does not hold and there is no simple expression for the value of I/I_o in terms of R/H and σ_H. The effect of the reflecting ceiling is shown in Fig. 5 where the collected results are plotted as I/I_o against C/H for given values of R/H and σ_H. Although limited in their extent these curves show that, at least for small values of σ_H, to a first approximation the maximum value of I/I_o for a given R/H is obtained when $R/H \approx 2\ C/H$.

For low values of σ at distances R = H the flux gain by scatter from the smoke and reflection from the ceiling is equal to the loss of flux by attenuation of the direct beam of light; so no net loss results. Even at distances of R = 8H the received flux can be as high as 30 per cent of that without smoke and with an absorbing ceiling.

The contribution of the reflecting ceiling is shown in Fig. 6 where the results of experiments with the two different ceilings are compared. It is evident that the enhancement of the flux due to ceiling reflection is increased as the distance from the source increases and as the smoke layer depth decreases. This flux increase varies from 1.5 times at a distance of 1 metre to some ten or twenty times at a distance of 8 metres with low smoke layers. An increase in the attenuation coefficient of the smoke produces a relative increase in the flux due to reflection from the ceiling. The broken curves of Fig. 6 are based on measurements where the photocurrents in the experiments with an absorbing ceiling were very small and any ratio, such as that now being discussed, based upon them is less reliable.

(b) Horizontal surfaces

The ratios of the fluxes on vertically upward facing surfaces (U) and forward facing surfaces (F) are shown in Figs. 7 and 8 for absorbing and reflecting ceilings respectively. In both cases the ratio U/F increases with increase in the attenuation coefficient. In the case of the

absorbing ceiling the ratio increases with smoke layer depth. The reflecting ceiling, whilst increasing the flux on the horizontal surface, also makes the ratio U/F almost independent of the smoke layer depth. With an absorbing ceiling the value of U/F is of the order of 0.1 for $\sigma = 1\ m^{-1}$ at all smoke layer depths, and rises to the order of unity for $\sigma = 5\ m^{-1}$ and a smoke layer depth of 1 m. There is a general increase in the value of U/F with a reflecting ceiling and it can be as high as 1.5.

(c) Surfaces facing away from the source

Figs. 9 and 10 show the values of the ratio of the flux on a backward facing surface (B) to that on the forward facing surface (F) for the various experimental conditions. The depth of smoke does not appear to have quite so marked an effect as in the case of the horizontal surfaces. With an absorbing ceiling there is a steady increase in B/F with distance from the source rising to about 0.3 at a distance of 4 metres for large values of σ. With a reflecting ceiling there is a more rapid initial rise after which the ratio goes through a maximum or reaches a constant value; this is about 0.4 for large values of σ and occurs at a distance of about 2 metres. The optical density of the smoke has an influence on B/F which increases with increasing σ. For smokes of $\sigma = 1\ m^{-1}$, B/F remains less than 0.1 except for the case when the smoke depth is equal to the height of the reflecting ceiling.

Derivation of an Empirical Equation

It was felt that an equation relating I/I_o, σ and R would be useful to summarize the influence of the two variables on the flux ratio. The results of the experiments with the absorbing boundaries was suitable for analysis as I/I_o was constant for σ and R in terms of H (Fig.3). To include two other variables, namely the height and albedo of the reflecting ceiling, and take into account the fact that I/I_o was not a simple function of σ and R in terms of layer depth (Fig. 4), would require more data than are available at present.

Visual inspection of these curves and trial-and-error fitting of appropriate functions of R and σ show them to be approximately fitted by the equation

$$\text{Log } I/I_o = -0.23\, \sigma_H^{0.6} \cdot (R/H)^{0.8}$$

Values of I/I_o computed from this equation are plotted as broken lines in Fig. 11. They compare fairly well with the experimental curves so that the equation can be said to give a useful indication of the influence of R and σ upon the flux ratio.

Comparison with measurements in the atmosphere

The previous report (1) suggested a "scaling" factor, relating the chamber experiment results to field measurements, of 2 metres in the chamber equivalent to 1 mile in the field. The smoke layer depth in the chamber was at this time restricted to 0.5 m and the scaled range to 4 miles. Variation of the smoke layer depth has made it possible to extend the chamber range to 16 units (1 unit being the depth of the smoke layer). If an effective natural atmosphere height is assumed the field ranges can be expressed in terms of this.

Scatter in the field results, due to variations in the meteorological conditions, necessitated the derivation of a set of empirical curves to describe the relations between flux, range and visibility in the atmosphere. These are given in Fig. 9 of Ref. (2). When these are reduced to ranges expressed in terms of assumed effective atmosphere heights, the flux is almost the same for any given value of the equivalent range. In other words, any assumed effective height of the atmosphere will produce as good a correlation with the chamber results as any other assumed height (within reasonable estimates of the atmosphere height).

Taking the curves of Fig. 9 of Ref.(2) at their face value, the relation between chamber results (F_o) and field measurements (Ff) is given by

$$Fo/Ff = (R/H)^{0.25}/_{1.3}$$

For the smaller values of R/H this approximates to unity and does not invalidate the scaling factor derived in Ref. (1) under the limited conditions then operative.

CONCLUSIONS

(1) For absorbing boundaries the ratio of flux in smoke of a given vertical transmission to flux without smoke is constant for a given ratio of distance to smoke layer depth.

(2) With a reflecting ceiling, of albedo 50 per cent at a height of 1.5 metres above an absorbing floor, the maximum value of the ratio of flux with smoke to flux without smoke is obtained when the ratio of ceiling height to smoke layer depth is approximately half the distance in metres.

(3) The enhancement of flux due to the reflecting ceiling increases with distance but is less marked for deep smoke layers than for shallow ones.

(4) Increase in smoke layer depth and attenuation coefficient for a relatively non-absorbing smoke increases the flux on an upward facing surface relative to that on a surface facing the source. In the presence of a reflecting ceiling this ratio can be as high as 1.5 : 1.

(5) The ratio of the flux received by a surface facing away from the source to that on a surface facing the source increases as the distance from the source increases. The smoke layer depth has a less marked effect than in the case of upward facing surfaces and the effect of the reflecting ceiling is to increase the ratio somewhat at shorter distances, but the increase becomes less at greater distances.

(6) An empirical equation which represents the experimentally determined values of the ratio of flux with smoke (I) to flux without smoke (I_o), with absorbing boundaries, fairly well is

$$\text{Log } I/I_o = -0.23\ \sigma_H^{0.6} \cdot (R/H)^{0.8},$$

where R is distance expressed in terms of the depth of the smoke layer and σ_H is the attenuation coefficient in units of (layer depth) $^{-1}$.

(7) A complete correlation between chamber experiment results F_o and field measurements F_f is not possible due to the lack of information on the effective height of the natural scattering atmosphere.

The relationship $F_o/F_f = (R/H)^{0.25}/_{1.3}$ is tentatively proposed.

ACKNOWLEDGEMENTS

J.B.D. Lovell assisted throughout these experiments and with the evaluation of results. Mrs. I.P.M. Creasey also assisted with the computations.

(Sgd.) H.L. Green,
Supt., Physics Research Division.

(Sgd.) A.S.G. Hill,
Deputy Director.

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(1)	N.W. Wootten and R.G. Dorman	1960	P.T.P. (R) 28
(2)	W.R. Lane, B.R.D. Stone and J. Edwards	1961	P.T.P. (R) 36
(3)	R.G. Dorman and N.W. Wootten	1958	P.T.P. (R) 14
(4)	N.W. Wootten and W.R. Lane	1961	P.T.P. (R) 34

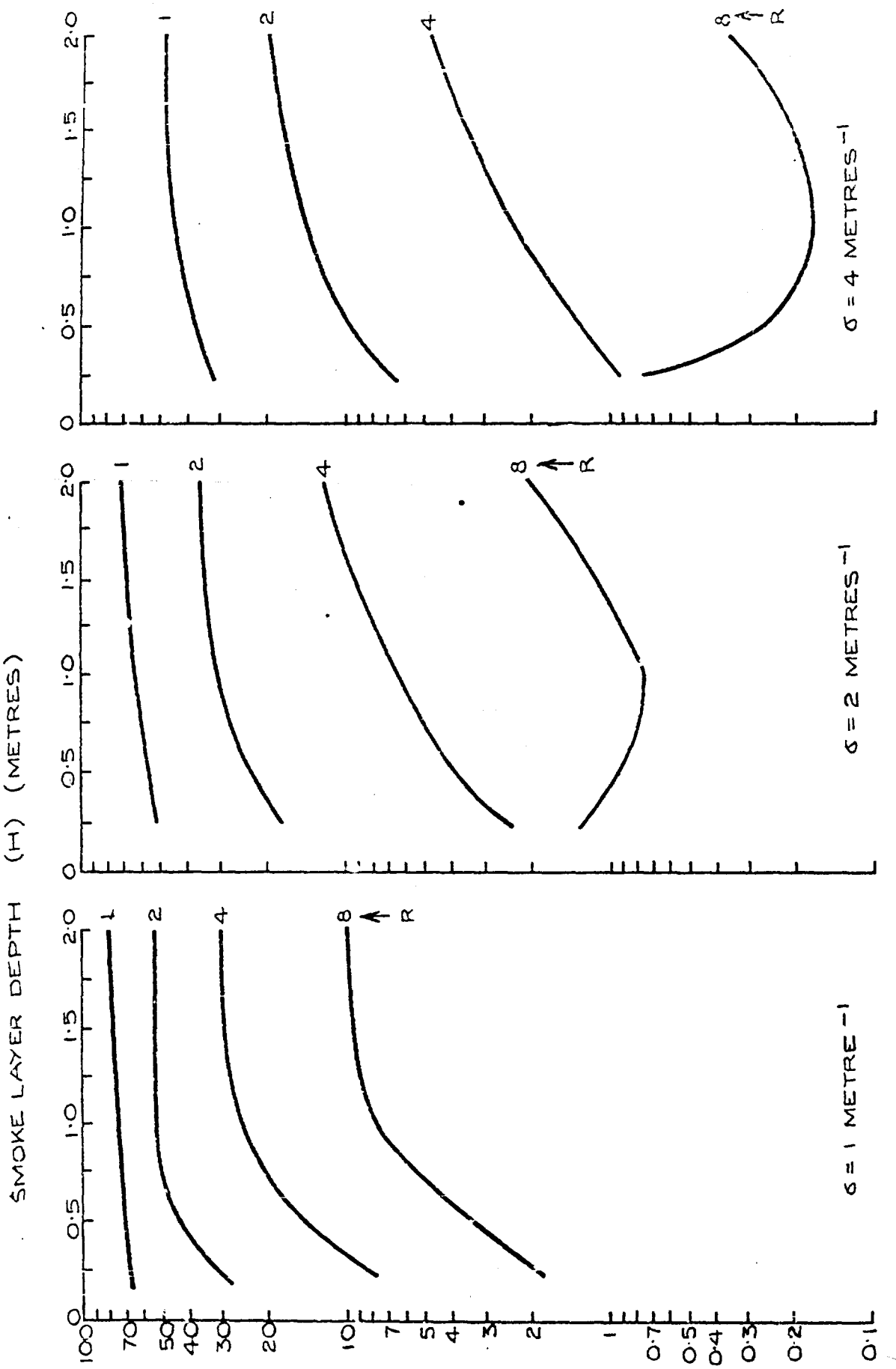

FIG. 1 FLUX ON FORWARD FACING SURFACE WITH ABSORBING CEILING

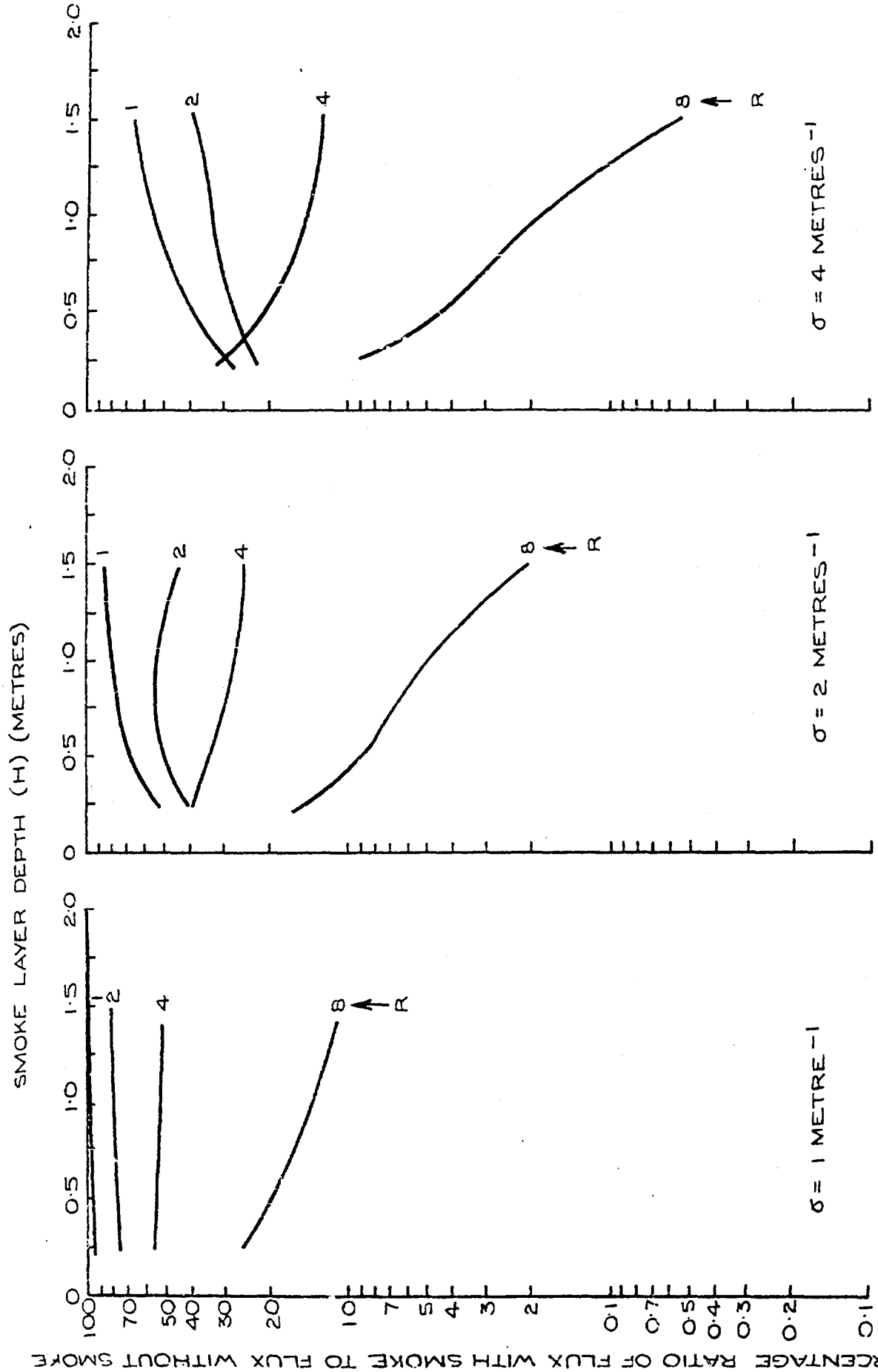

FIG.2 FLUX ON FORWARD FACING SURFACE WITH REFLECTING CEILING.

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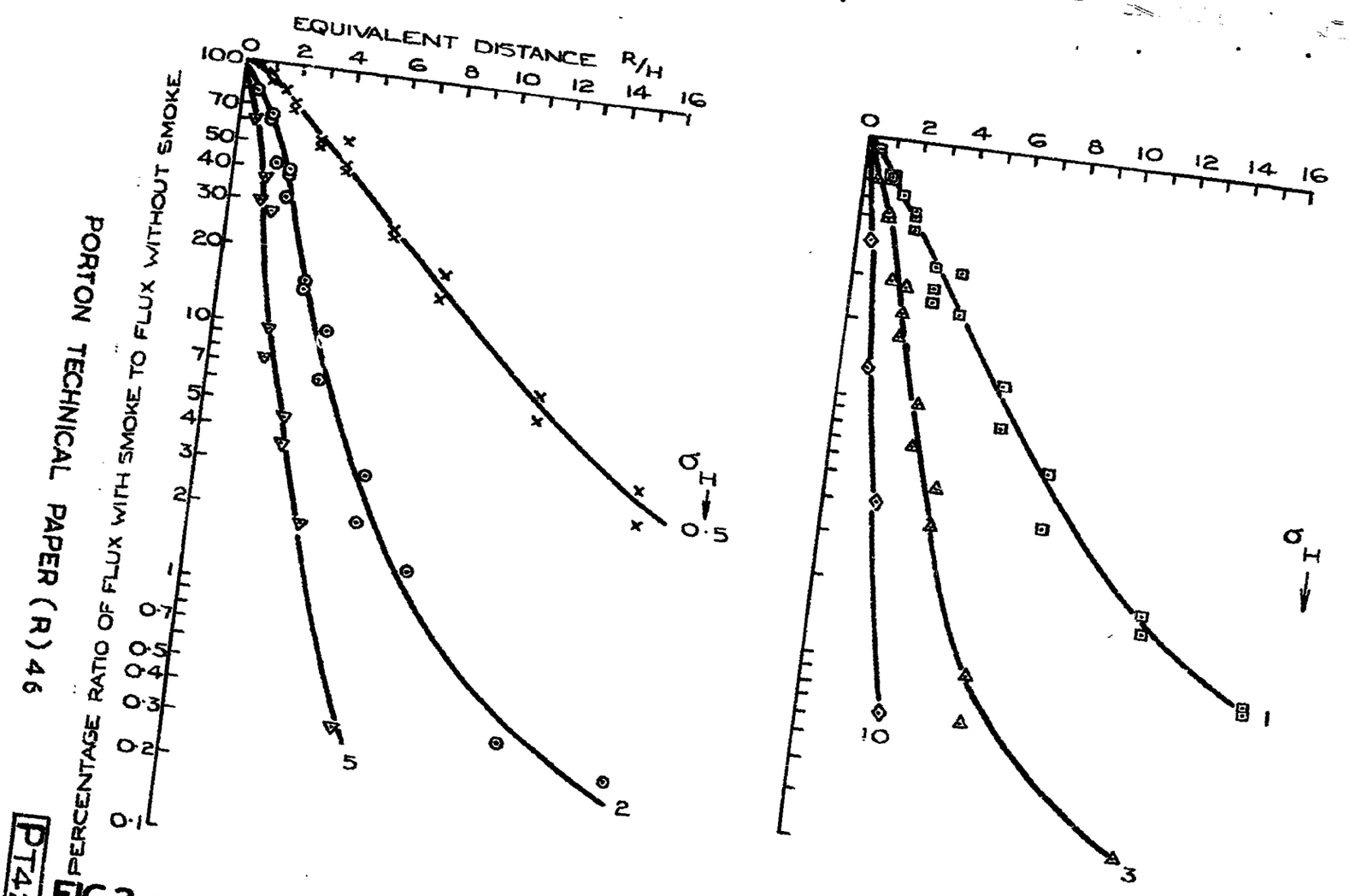

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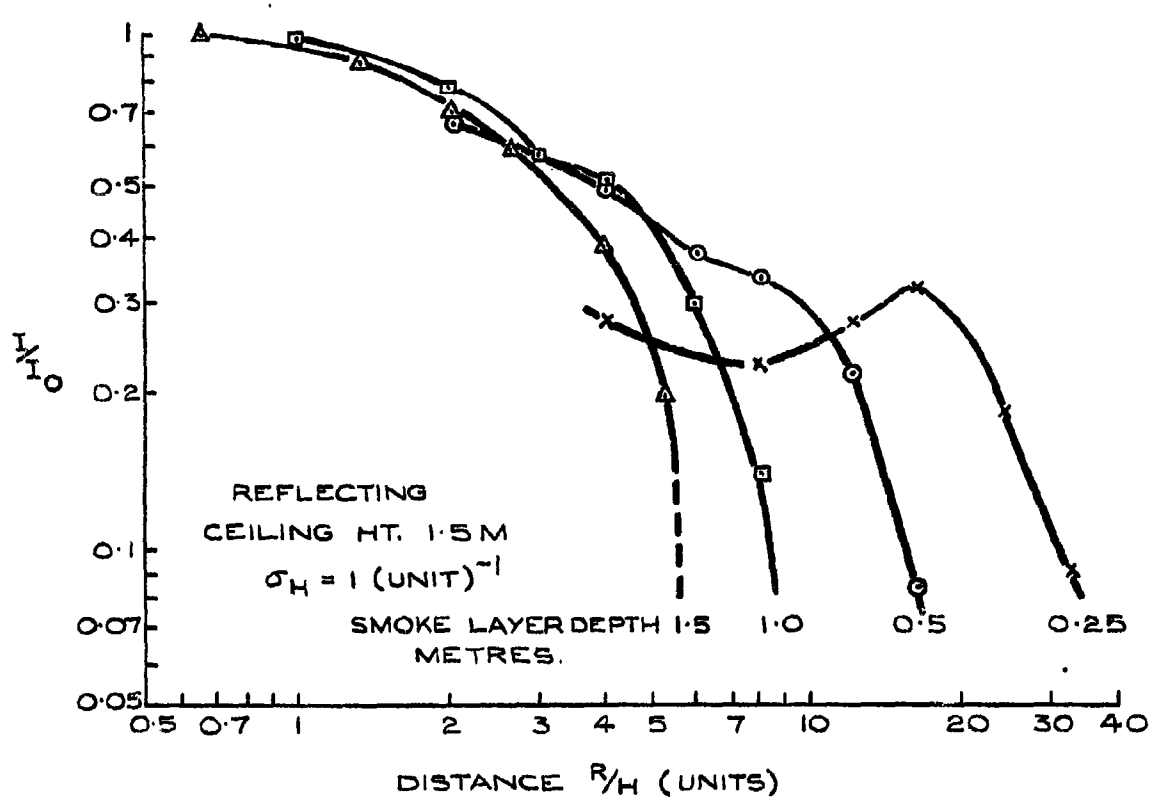
FIG.3 THE COLLECTED RESULTS OF EXPERIMENTS WITH ABSORBING BOUNDARIES



TYPICAL RESULTS WITH A REFLECTING CEILING SHOWING NON-LINEAR RELATION WITH CHANGE OF SMOKE LAYER DEPTH.

FIG. 4.

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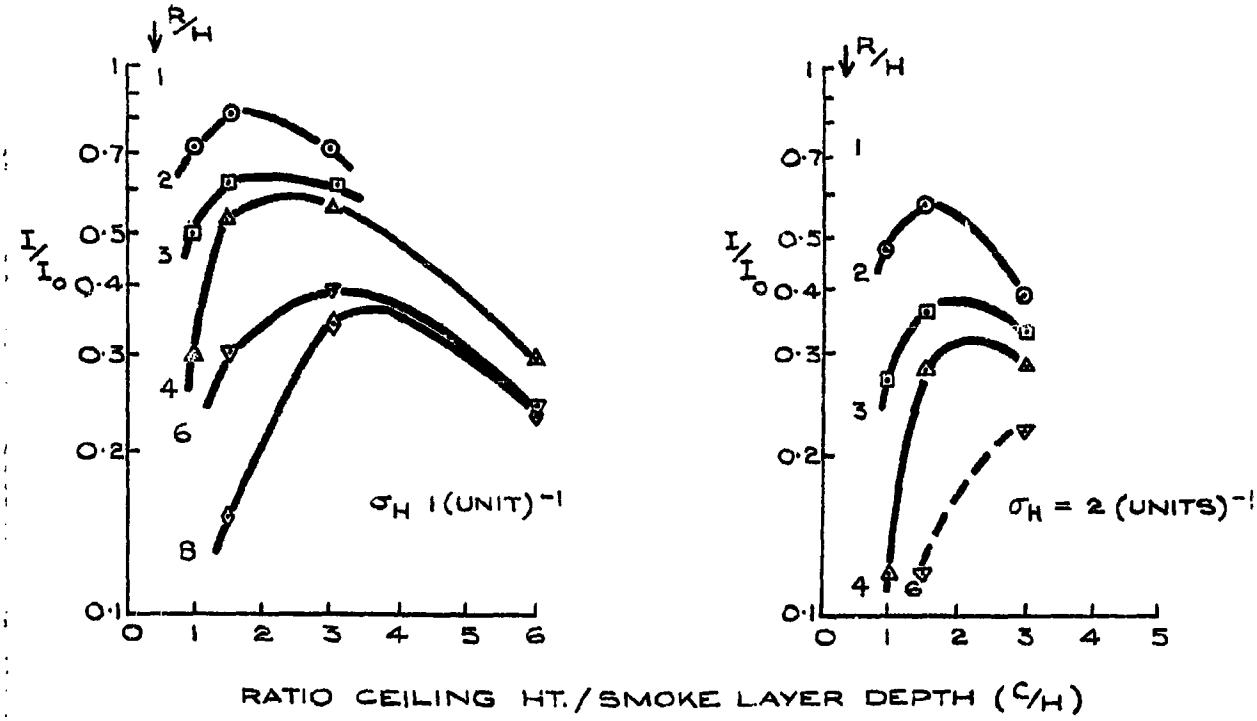
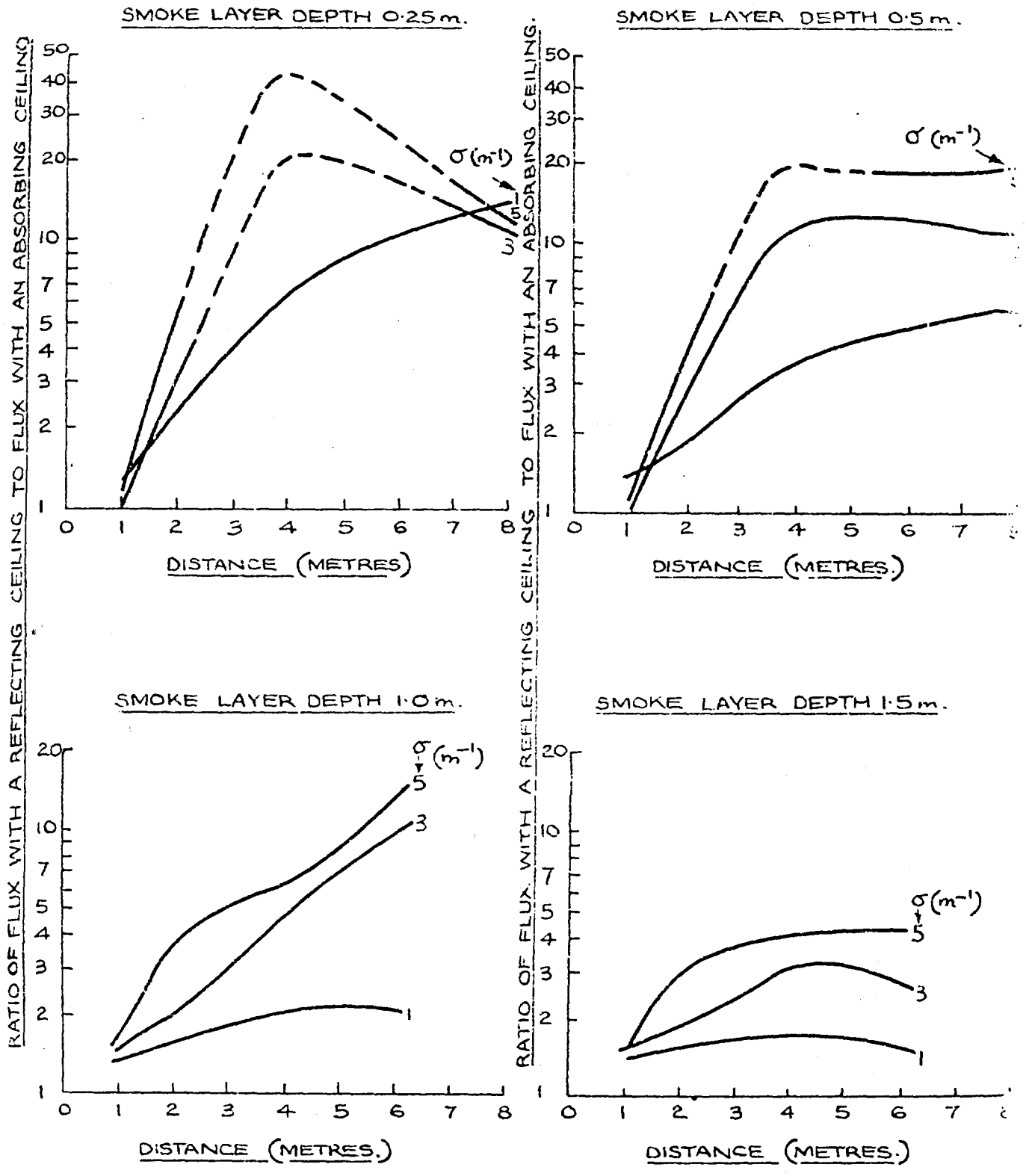


COLLECTED RESULTS OF EXPERIMENTS WITH A REFLECTING CEILING.

FIG. 5.



SHOWING THE INCREASE OF FLUX
DUE TO THE REFLECTING CEILING.

FIG. 6.

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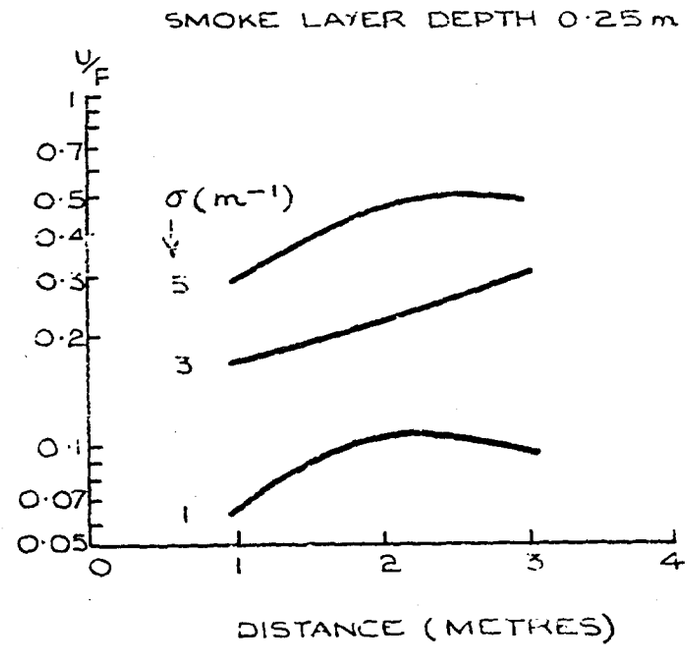

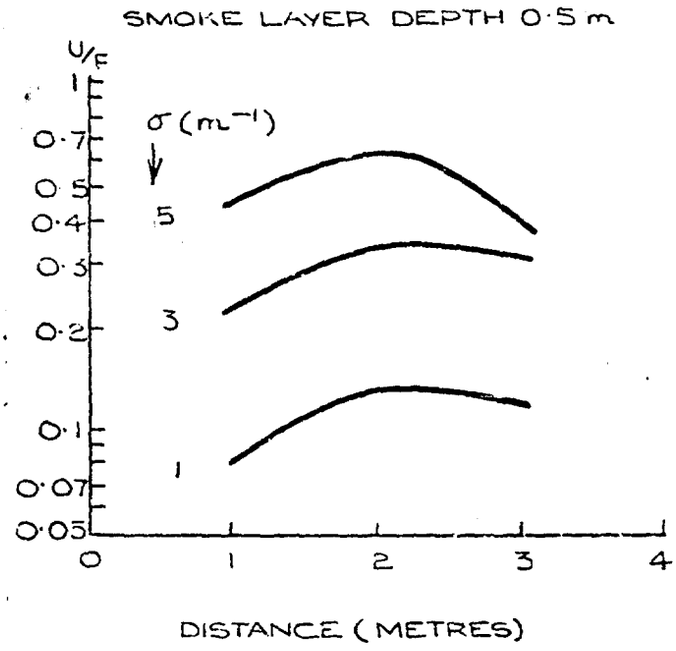

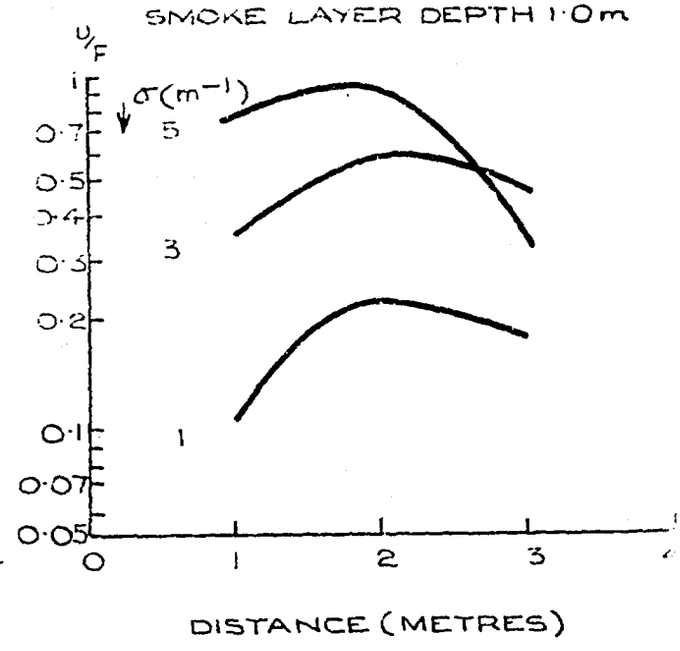

RATIO OF FLUXES ON UPWARD FACING SURFACES (U)
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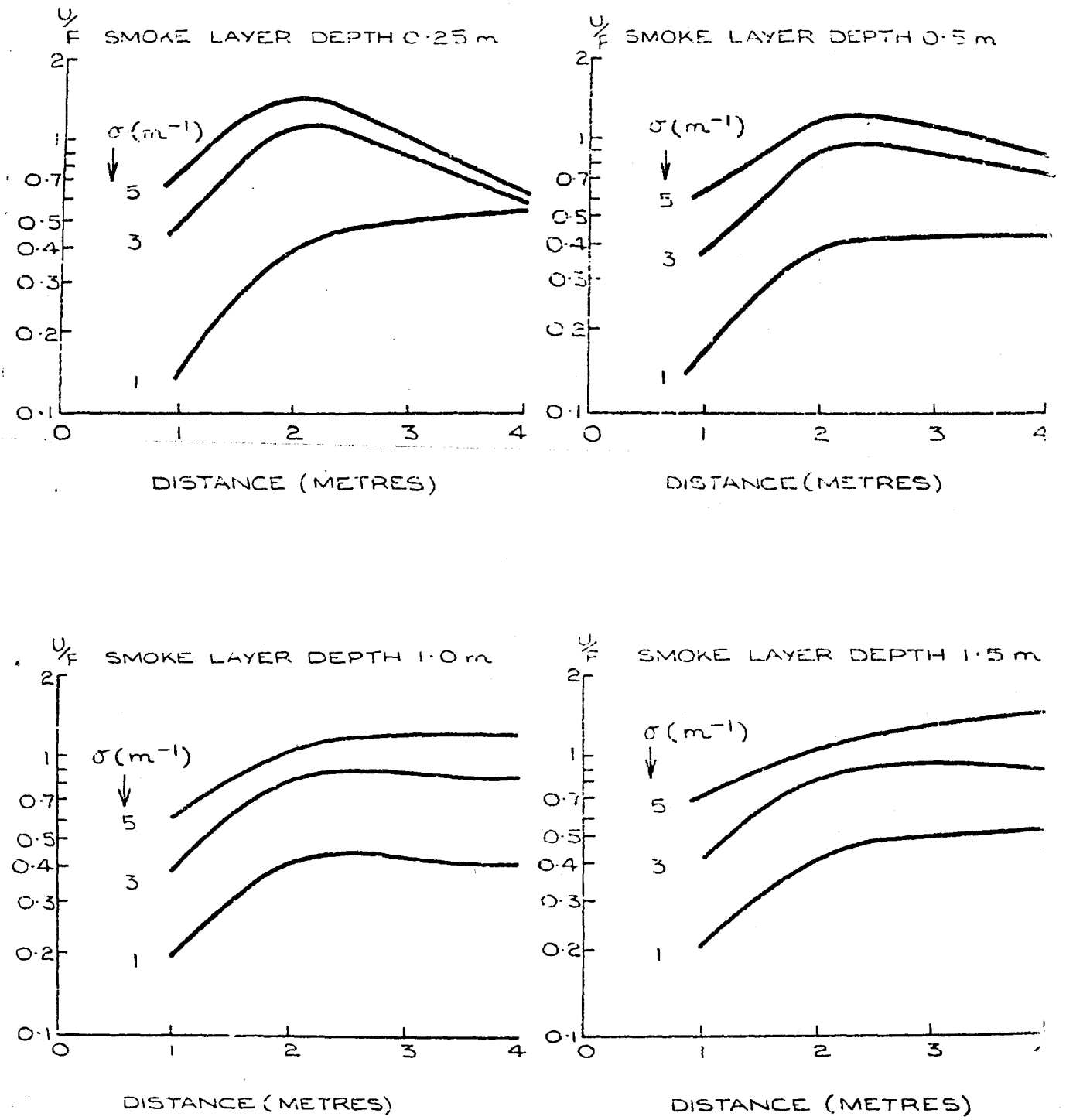
FIG. 7.



RATIO OF FLUXES ON UPWARD FACING SURFACES (U)
TO THOSE ON FORWARD FACING SURFACES (F)
WITH A REFLECTING CEILING.

FIG. 8

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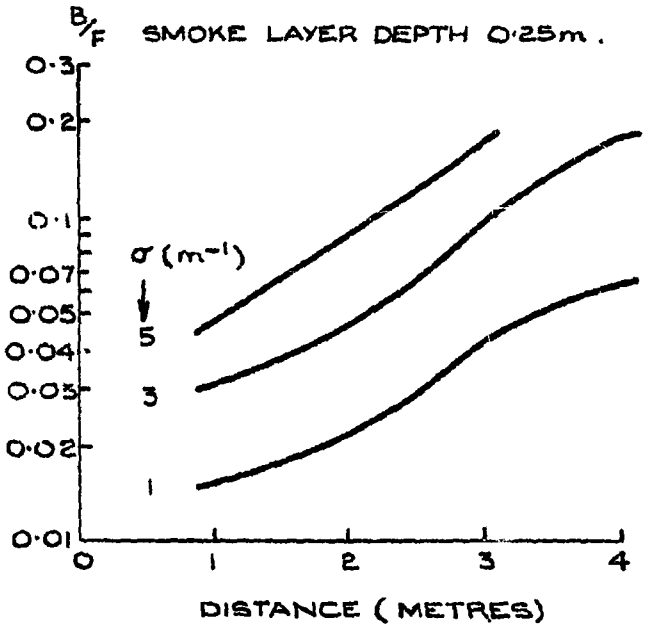
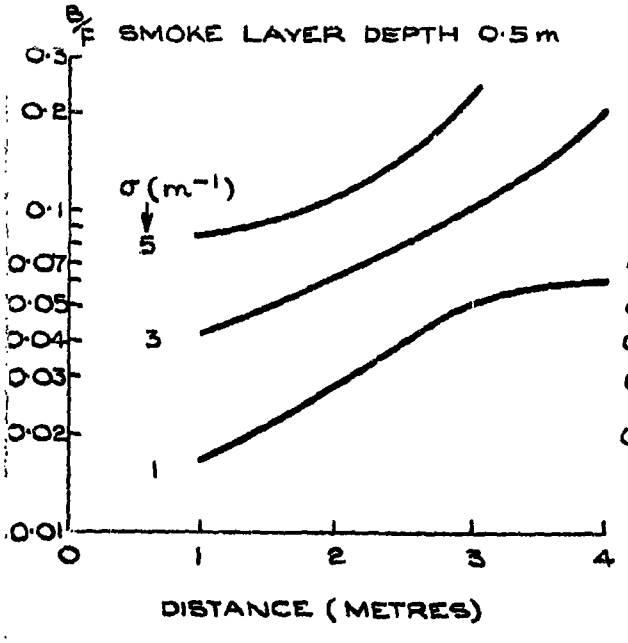
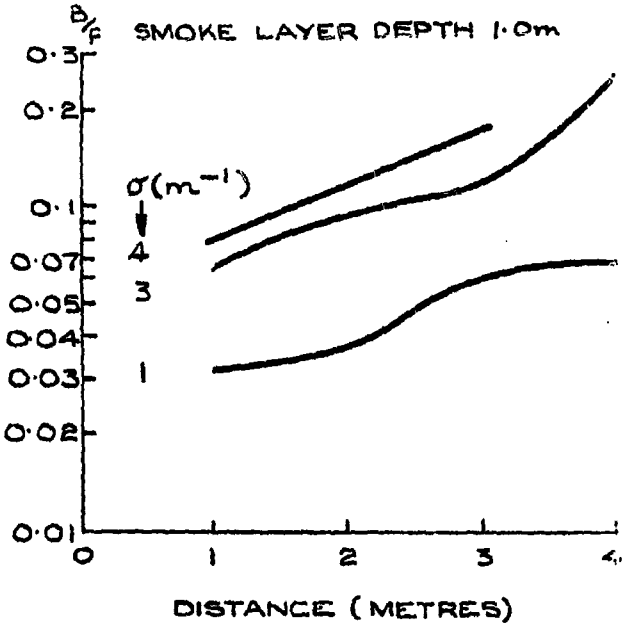
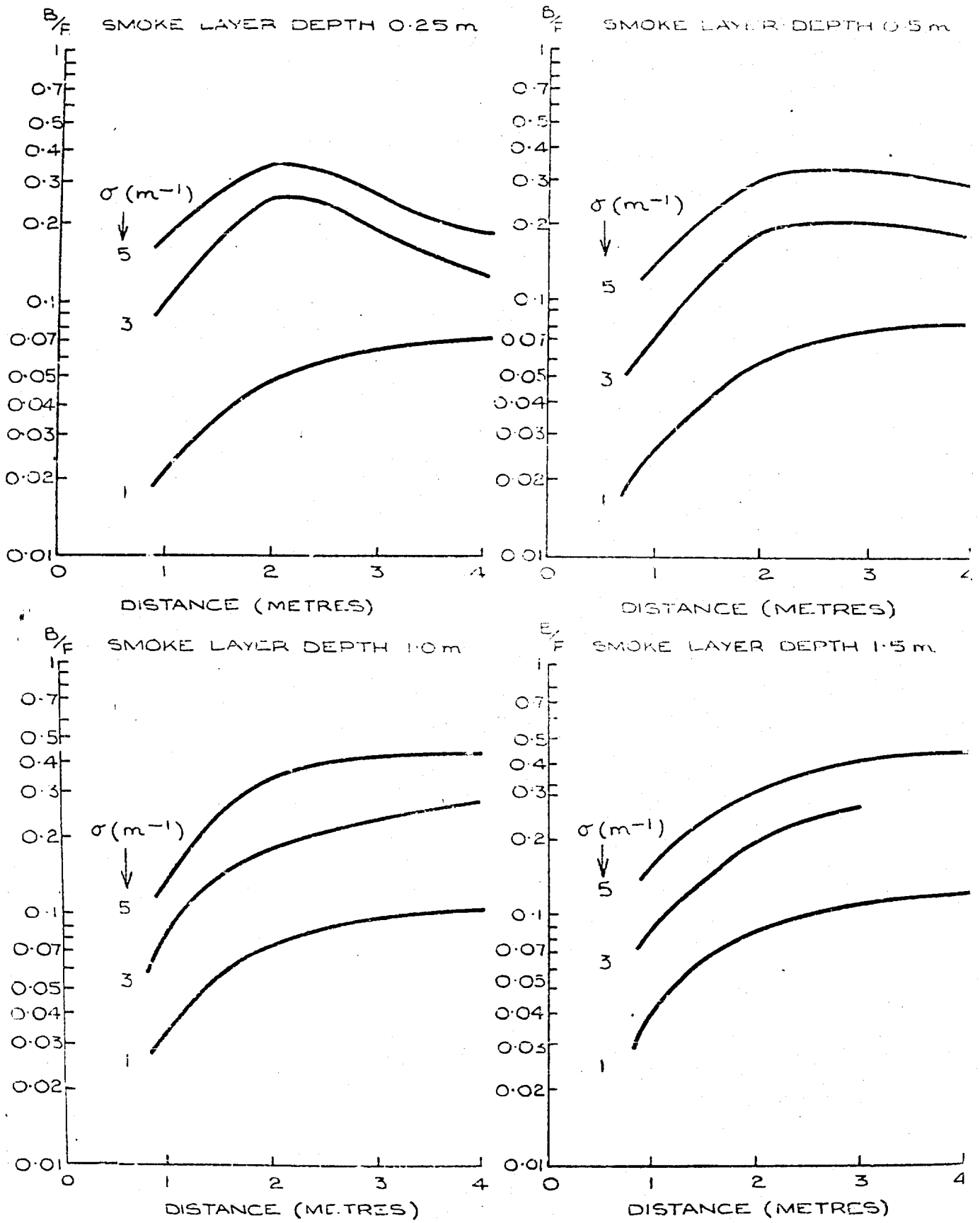






RATIO OF FLUXES ON BACKWARD FACING SURFACES (B) TO THOSE ON FORWARD FACING SURFACES (F) WITH AN ABSORBING CEILING.

FIG. 9.



RATIO OF FLUXES ON BACKWARD FACING SURFACES (B) TO THOSE ON FORWARD FACING SURFACES (F) WITH A REFLECTING CEILING.

FIG. 10

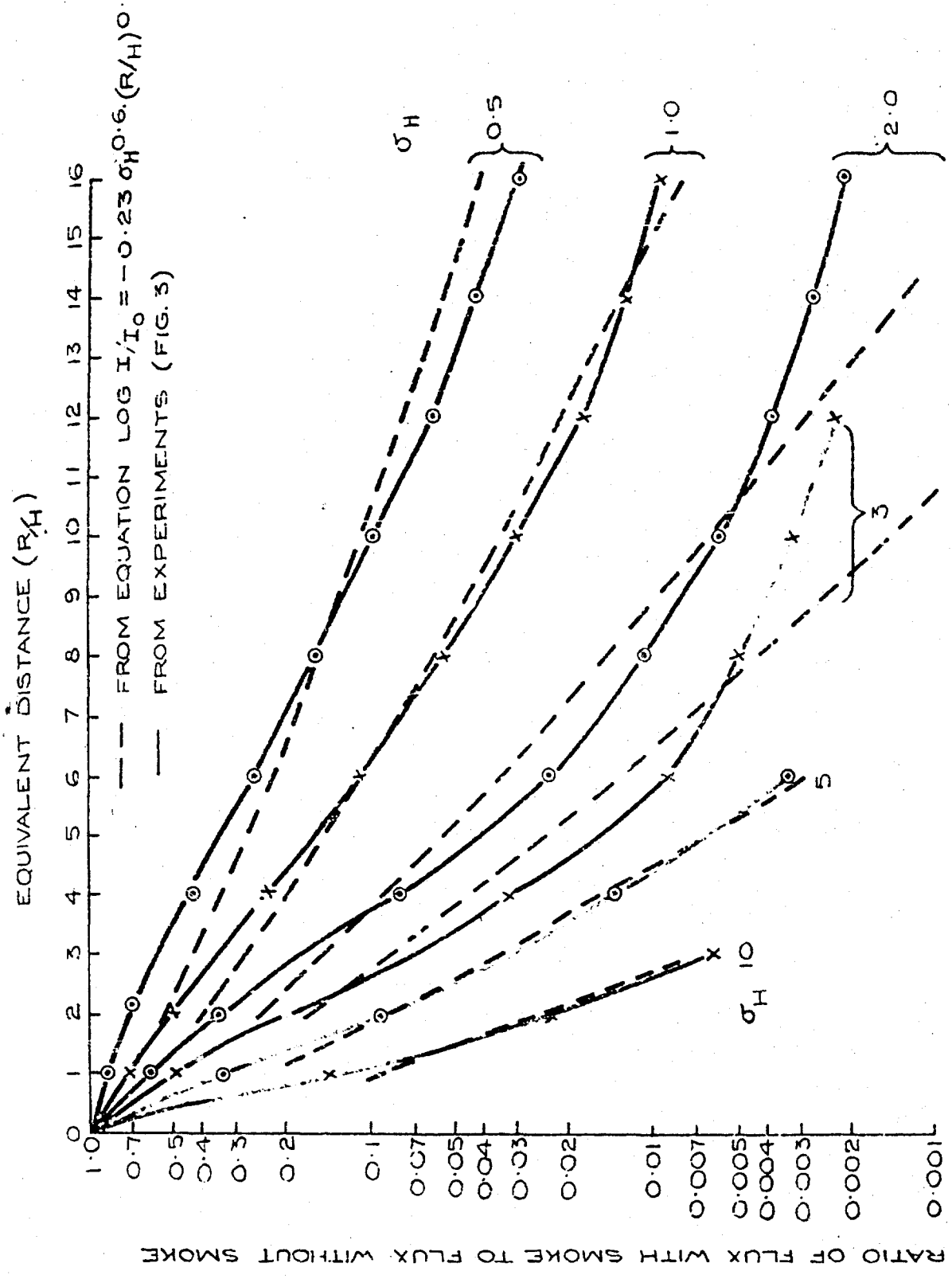


FIG. 11. COMPARISON OF EMPIRICAL EQUATION WITH EXPERIMENTAL RESULTS.

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12. *(TITLE, REPORT NUMBER, AUTHOR(S))* The influence of smoke layer depth on the attenuation of light in a simulated scattering atmosphere. PTP- Wootten, N.W.; Lane, W.R.

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Title: INFLUENCE OF SMOKE LAYER DEPTH ON THE ATTENUATION OF LIGHT IN A SIMULATED SCATTERING ATMOSPHERE

AD Number: AD0332435. *Corporate Author:* CHEMICAL DEFENCE EXPERIMENTAL ESTABLISHMENT PORTON DOWN (ENGLAND). *Personal Author:* WOOTTEN,N.W. LANE,W.R.. *Report Date:* September 01, 1962. *Media:* 1 Page(s). *Distribution Code:* 13 - U.S. GOVT. ONLY; NON-DOD CONTROLLED. *Source Code:* 080450. *From the Collection:*

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